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Comparative Analysis of Three-Phase AC-DC Converters Using HIL-Simulation

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Abstract

This paper presents a comparative evaluation of various topologies for three-phase power converters using the hardware-in-the-loop (HIL) simulation technique. Various switch-mode AC-DC power converters are studied, and their performance with respect to total harmonic distortion (THD), efficiency, power factor and losses are analyzed. The HIL-simulation is implemented in an Altera Cyclone II DE2 Field Programmable Gate Array (FPGA) Board and in the Matlab/Simulink environment. A comparison of the simulation and HIL-simulation results is also provided.

Key words: FPGA, Hardware-in-the-loop (HIL), Simulation, Three-phase AC-DC converters

I. INTRODUCTION

The advances in power semiconductor devices have catapulted numerous studies on pulse width modulation (PWM) techniques to improve the quality of sinusoidal input current so that the current adheres to harmonic standards such as IEEE Std. 519, IEC 1000-3-2 and IEC 61000-3-2. As a result, a significant number of PWM switch-mode AC-DC power converters have been proposed to replace conventional diode rectifiers to achieve a pure sinusoidal input current with a low total harmonic distortion (THD) and a unity power factor [1]-[5]. Various topologies such as buck, boost, and buck-boost have been developed so that the output voltage can be controlled to a desired value while reducing harmonic currents.

For low and medium voltage DC loads requirements, buck switch-mode rectifiers have been proposed to step-down the output voltage [3], [6]-[8]. However, these converters are not suitable for step-up voltage conversions. To produce a high DC voltage, boost rectifiers have been proposed in [9]-[11]. Due to inductors placed in series with the inputs, boost converters draw a continuous current flow and contain a low switching frequency content. These features give boost converters an advantage over current-source buck converters, which draw pulse width modulated currents [12]. However, recent technological developments require power supplies with wider conversion rates especially in photovoltaic applications and electric vehicle technologies. Wider conversion ratios can be obtained by adjusting the modulating control signal of the converter. In practice, the attainability of the conversion ratios is limited, especially when the duty ratio is nearing 0 or 1. As a result, major deterioration of the output voltage and inductor current signals occur. Another approach is the use of transformers to step-up/down the DC output. However, limited power capacity, design complexity, poor cross regulation, and high inrush currents are some of the drawbacks of using a transformer [13]. To achieve a wider conversion ratio, cascaded converters have been proposed, where two or more converters are connected together in a multistage operation [13]-[16].

Progress in digital technologies such as field programmable gate arrays (FPGAs) has enabled engineers to develop complex controllers without considerable hardware modifications. The integration of software and a FPGA for real-time simulation has been done in [17]-[19]. Hardware-in-the-loop simulation is a tool for the implementation and verification of a controller's functionality without increasing the risk of damaging the prototype during actual testing. Moreover, conventional simulations do not consider the resolution limit of the processor chip. By implementing a discretized model for simulation accuracy, the controller design can be tested under realistic conditions.

In this paper, a performance study of various AC-DC converters based on HIL-simulations is presented. The simulation model is done in the Matlab/Simulink environment. An Altera DSP Builder, containing high-level algorithm very-high-speed hardware descriptive language (VHDL), is integrated with the Simulink blocks to create a hardware/software co-simulation model. The comparison is done with respect to the converters' efficiencies, the total

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